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A POSSIBLE QUANTITATIVE USE OF MEAN CIRCULATION CONCEPTS IN DAILY FORECASTING

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ABSTRACT

The question of the operation of large-scale controls in day-to-day weather map evolutions is discussed. To explore the usefulness of these concepts in daily forecasting, the problem of forecasting the passage of summertime cold fronts at Kansas City is used. More-or-less standard techniques are used to develop an objective method of forecasting these frontal passages, and its deficiencies are discussed. A technique employing certain aspects of the 5-day mean 700-mb. chart as a means of eliminating these deficiencies is investigated. Results suggest that it is possible to use certain features of a prognostic 5-day mean 700-mb. chart to improve on the results of an objective forecasting method.

INTRODUCTION

The question of long-term and large-scale weather controls has long been examined. Baur [1] discusses long-range weather controls (*Grosswetter*) and sets forth nine "empirical theorems" substantiating the reality of the concept. Further, he defines the term *Grosswetterlage* as "the mean pressure distribution (at sea-level) for a time interval during which the position of the stationary (steering) cyclones and anticyclones and the steering within a special circulation region remain essentially unchanged." He adds that restriction to mean surface pressure distribution is necessary in order to be able to apply the definition to the years before aerological observations were available, but that the existence of such Grosswetterlage imply constancy of pressure distribution in the middle troposphere.

Namias [2] reasons at some length on the reality of these large scale controls and says:

Yet the interrelationship [between tracks of cyclones and anticyclones, and centers of action] does not *prove* that the behavior of the individual systems of the daily maps is determined by the centers of action .... At present there seems to be no satisfactory method of proving the causal and governing nature of the centers of action as opposed to the view that they are only statistical reflections .... It seems to the author [Namias] that the moderate success obtained in predicting 30-day average circulation patterns from preceding sequences of such patterns is an indication of *physical reality of the means*. [These last italics supplied.]

If there is an element of reality in these concepts of Grosswetterlage, they should rightfully be a necessary adjunct in the entire field of daily forecasting. With these views in mind, a possible objection to a number of objective forecasting methods which have been devised lies in the fact that they are developed from a group of data taken from a variety of Grosswetter regimes. This would seem to be disadvantageous on two points:

1. Unless one deliberately sets out to include a full range of Grosswetter types in the developmental *and* the test data, a test is likely to indicate a breakdown of the objective method, not necessarily because of the lack of effectiveness of the variables used, but simply because the developmental and test data comprise predominantly different Grosswetter types. This is particularly true when the developmental sample comprises one time series of data, and the test sample another.
2. If a variety of Grosswetter types are included in the developmental data, discrete grouping of the elements to be forecast becomes difficult to achieve because the predictor variables tend to exert influences which vary from one type to another.

The purpose of this paper is to explore the applicability of these concepts of large-scale controls to the daily forecast problem. An assumption that is suggested may be stated as follows: There exist large-scale features of the circulation which exercise some control over certain features of the daily maps, and further, these large-scale features are at least partly portrayable by maps of time averages of pressure, or height of a pressure surface.

SELECTION OF SPECIFIC FORECAST PROBLEM

To investigate the utility of these concepts in the daily forecast, the problem of predicting cold or occluded front passages at Kansas City was chosen. While the choice was somewhat arbitrary, still there are certain aspects of the problem which make it a reasonable choice. By dealing with fronts already in existence, the question of their subsequent movement becomes more closely allied with the flow itself rather than a thermodynamic problem such as would be the case if precipitation or cloudiness had been chosen.

DEVELOPMENT OF FORECASTING METHOD

DATA SELECTION AND INITIAL STRATIFICATION

Cases of the 1230 GMT surface chart in which a cold, stationary, or occluded front occurred within the area indicated in figure 1 were chosen as the basic data. The specific problem was whether or not these fronts would pass Kansas City within the subsequent 24-hour period. The summer months—June, July, and August—were con-

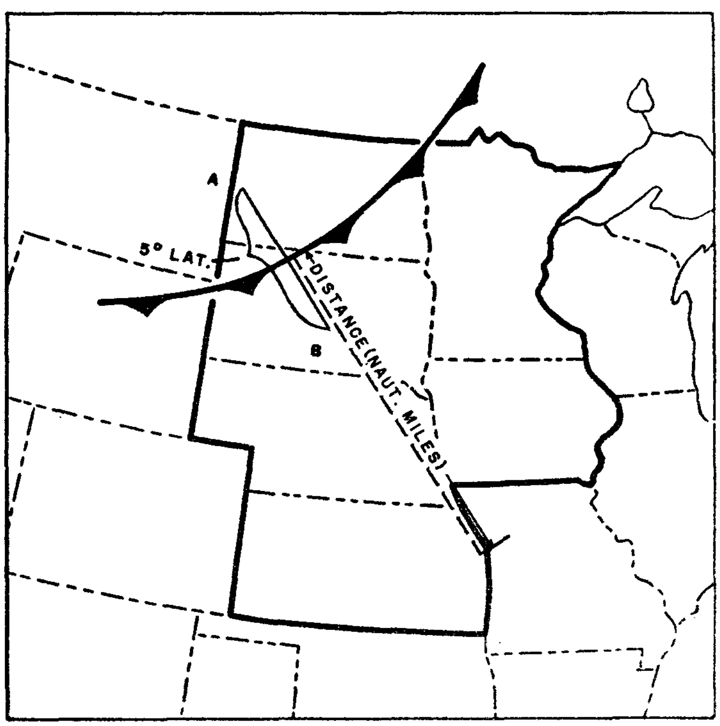

FIGURE 1.—Schematic illustration of basic data tabulation. Cases of the 1230 GMT surface map selected when a cold, occluded, or stationary front appeared within outlined area. Elements tabulated were (1) shortest distance between front and Kansas City (in nautical miles); (2) isallobaric gradient across front, i. e., 3-hour tendency at A minus 3-hour tendency at B (interpolated if necessary); and (3) whether or not front passed Kansas City within the following 24 hours.

TABLE 1.—*Percentage of total frontal cases in which front passed Kansas City within subsequent 24 hours, by groups from figure 2*

	Dependent period June, July, August 1947–50	Test period June, July, August 1951–53 (except July 1951)
Group 1	2	2
Group 2	18	8
Group 3	30	24
Group 4	64	55
Group 5	89	79

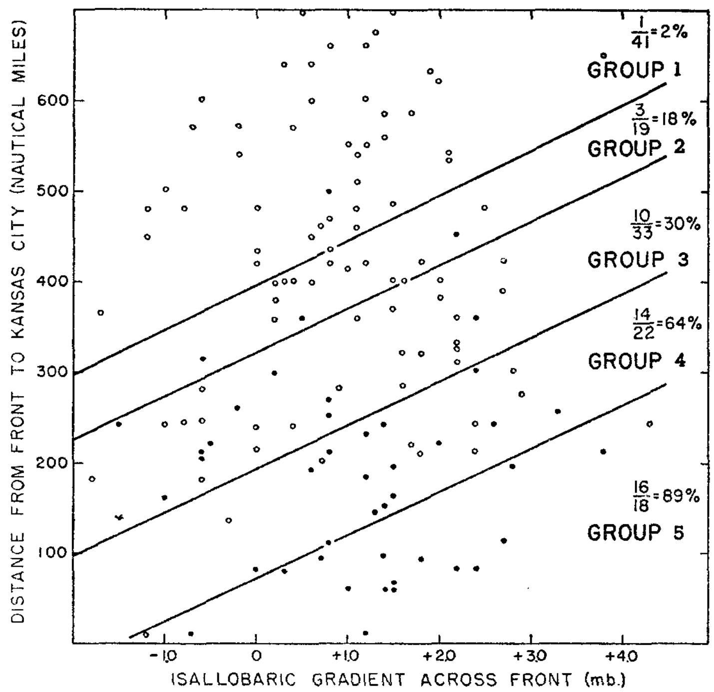

FIGURE 2.—Scatter diagram relating distance from Kansas City to the front and the isallobaric gradient across the front (both measured from 1230 GMT surface chart) to the subsequent passage (•) or non-passage of that front at Kansas City. Ratios are number of cases of passage (numerator) to total number of cases in group. Data from June, July, August 1947-1950 inclusive.

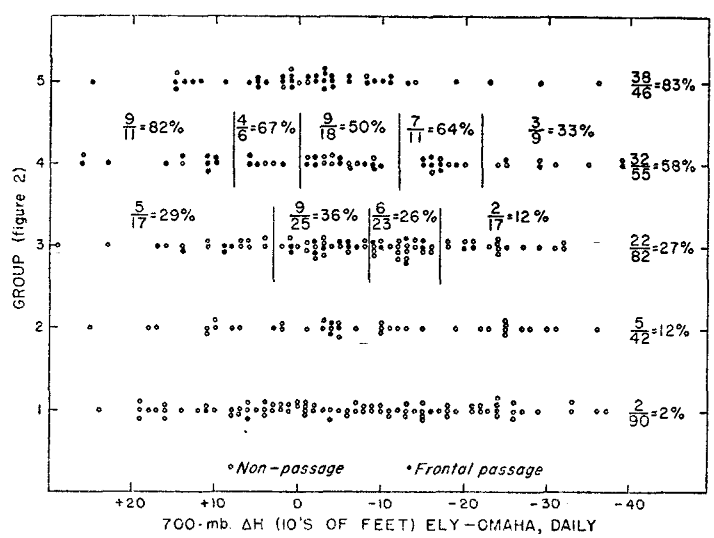

FIGURE 3.—Scatter diagram relating initial stratification as determined from 1230 GMT surface data (fig. 2) and the difference in 700-mb. height from Ely, Nev., to Omaha, Nebr. (Ely minus Omaha), taken from 0300 GMT 700-mb. chart of same date as surface chart, to the subsequent passage or non-passage of the front at Kansas City. Ratios are number of passages (numerator) to total number of cases in group or subsection Data from June, July, August 1947-1953 inclusive, except July 1951.

sidered. The cases selected were stratified on the basis of (1) shortest distance between the front and Kansas City, and (2) isallobaric gradient across the front as illustrated in figure 1. This gives a basic stratification (fig. 2) which from table 1 appears to be real.

SUB-STRATIFICATION

It is reasonable that a northerly component of wind in the middle or lower troposphere across the Northern Plains would be conducive to the southward movement of a front in that area. Conversely a southerly component of wind would impede southward movement. After several different indices had been tried, the 700-mb. height difference between Omaha, Nebr., and Ely, Nev., was chosen as an index of meridional flow. A strong southerly component would be reflected in the height at Omaha being much greater than the height at Ely (negative index). Thus, the basic groups were sub-stratified on the basis of this ΔH index (fig. 3).

DEFICIENCY OF ΔH INDEX IN SUB-STRATIFICATION

Figures 2 and 3 in themselves constitute the basic approach used widely in development of objective forecast methods. In this case there is a time lag built into the system.[1] Also in this case (referring to fig. 3), implicit in the use of the ΔH index is the fact that it not only indicates the meridional flow at the synoptic time at which data are taken, but it *also* indicates an assumed characteristic variation in the meridional flow between that synoptic time and the end of the forecast period. This variation might be zero, or of considerable magnitude; it might be known or unknown, but it is implicitly constant for each value of the ΔH index. In the past the fallacy of this assumption of constancy has been recognized, but usually one who devises an objective forecast method has resigned himself to the inclusion of errors inherent in the assumption.

In figure 4 are plotted the once-per-day values of the ΔH index and the 5-day mean ΔH for August 1952, this month having been chosen at random. We see that there is little consistency in the way that the daily ΔH changes from one day to the next when the curve is taken by itself. However, in 24 out of 30 cases, the 24-hour change was *toward the 5-day mean.* This is not at all surprising because of the interdependence of the mean and its components. It does, however, suggest the possibility of using a prognosis of some mean index in enabling us to avoid the assumption mentioned above.

MODIFICATION OF ΔH INDEX

For forecasting purposes, Group 5 yields a sufficiently high probability of frontal passage to be used without further stratification. Similarly Groups 1 and 2 contain a proportion of non-passage cases high enough so that a

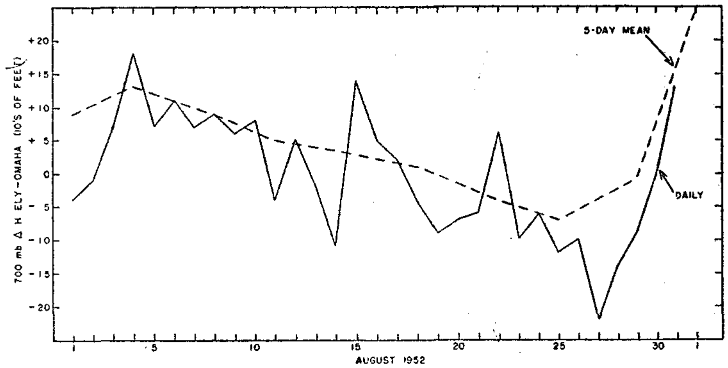

FIGURE 4.—Graph showing variations of the daily 700-mb. ΔH index (Ely minus Omaha), taken from the daily 0300 GMT 700-mb charts, and the mean 5-day 700-mb. ΔH taken from the observed 5-day mean 700-mb. chart and plotted at the middle date of the 5-day period. Data from August 1952, this month having been selected at random.

more complete separation is not necessary. Groups 3 and 4, however, must be considered somewhat indeterminate groups in which further stratification would be useful.

It has been pointed out that it would be reasonable to assume that modifying the daily ΔH index by the mean 5-day index would permit a more complete separation of the passage from the non-passage cases. This has been done for Groups 3 and 4. The 5-day ΔH index used was taken from the observed 5-day mean 700-mb. chart for the period including the day in question. The mean charts are computed twice weekly for overlapping periods. For cases falling within the overlap, the mean chart used was that whose central date was closest to the date in question. If the case date was equally close to both, the later mean chart was used. The results are figures 5 and 6.

A large negative 5-day mean ΔH index might be interpreted as representing the situation where a "long wave" trough is situated over the western portion of the United States, or even the eastern Pacific, with a relatively large-amplitude ridge downstream. Also, the difference between the daily and the 5-day mean index might, in a broad sense, be interpreted as an indication of the phase relationship between the long-wave and the short-wave patterns. The greater the difference, the greater would be the indicated phase difference.

While the cases in Group 3 (fig. 5) do not fall into distinctive groups, yet it is possible to construct a line of separation (solid line) which divides the sample into two groups of quite different overall passage to non-passage ratios.

Because of sparsity of data in the upper central portion of the chart, the line of separation in this area is uncertain. However, the general area of higher probability of frontal passage (Area I) is in the portion where the ΔH index is favorable for frontal passage and when modified by the 5-day mean index, should remain favorable. In other words, there is a long-wave trough to the east and a long-wave ridge to the west, and the short-wave pattern is not materially out of phase with the long-wave pattern.

[1] Upper air data are taken from 0300 GMT observations while the "forecast period" ends at 1230 GMT the following day. Thus, the time-lag period for this variable can be as much as 33½ hours.

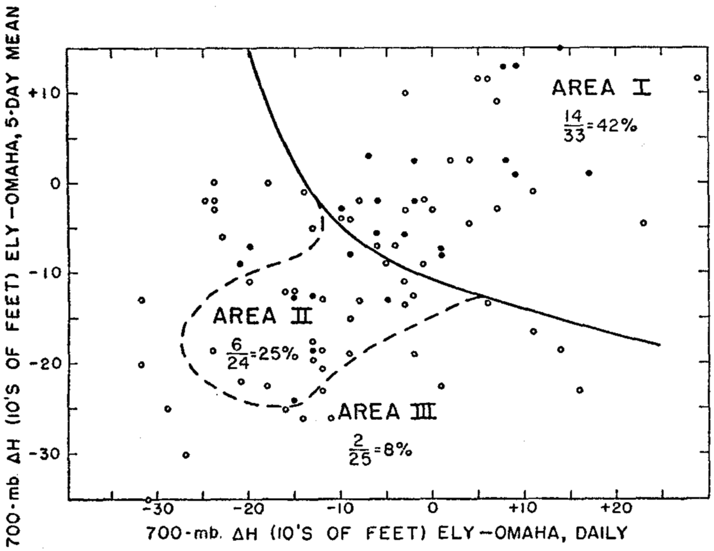

FIGURE 5.—Scatter diagram for Group 3 cases (fig. 3) relating the daily 700-mb. ΔH index (as described in fig. 3) and the 5-day mean 700-mb. ΔH index (Ely minus Omaha on observed 5-day mean 700-mb. chart) to the subsequent passage (•) or non-passage of the front at Kansas City.

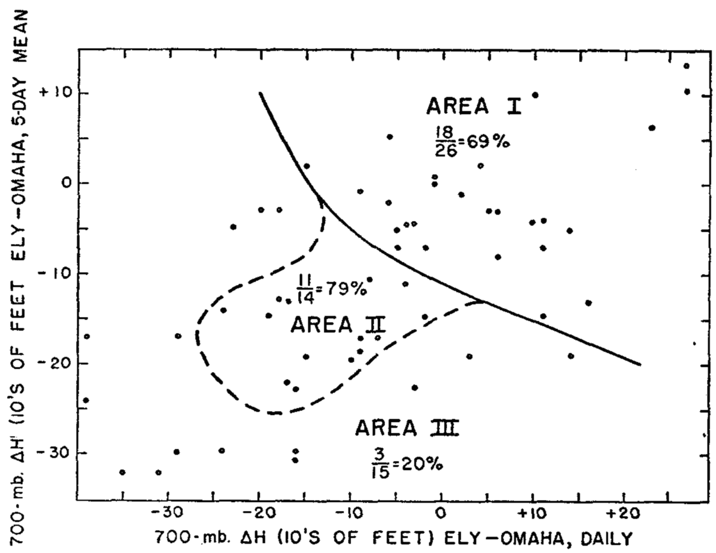

FIGURE 6.—Scatter diagram for Group 4 cases (fig. 3) relating daily 700-mb. ΔH index and 5-day mean 700-mb. ΔH index to subsequent passage (•) or non-passage of front at Kansas City.

In the lower right-hand portion of the chart, although the daily ΔH index is favorable for frontal passage, the 5-day mean index indicates that the daily index is changing toward one less favorable within the time-lag period. Stated in another way, while the distribution of short-wave troughs and ridges appears to be favorable for frontal passage, the long-wave pattern is unfavorable. In that portion of the chart few of the cases are those in which the front passed.

If the same line of separation (solid line) as that determined by the cases in Group 3 is used in Group 4, a separation is achieved, but it is not the best one. Area II in figure 6 contains an even higher proportion of frontal passage cases than Area I. This same area (determined by cases in Group 4) when transposed to Group 3 affords a further separation into a somewhat intermediate proportion of passage to non-passage cases. (See table 2.) Thus it appears that there are three areas, coincident in Group 3 (fig. 5) and Group 4 (fig. 6) each of which contain more or less homogeneous cases.

Area II represents, in terms of the variables, situations in which the daily ΔH index is slightly unfavorable, and when modified by the 5-day mean ΔH, little change is indicated through the time lag period.

TESTS

Basically, the aim of tests normally used in connection with an objective method is to determine the degree of homogeneity between two particular samples of data, one sample being the dependent data and the other the independent or test data. Much emphasis is usually placed on the final step or chart if a series of steps or charts is involved. It is generally assumed that if in this final chart or step there appears to be a certain amount of homogeneity between the two groups of data, then validity of all the relationships between the predictor variables and the forecast element is considered demonstrated. But tests that show homogeneity between two independent samples of data at all intermediate steps should be equally valid. In this light, let us briefly consider what has been done thus far:

1. In the initial stratification (fig. 2) homogeneity is demonstrated by an independent test with usual methods, using more cases than were in the dependent group (table 1). On the basis of this test the validity of the stratification is assumed and thereafter both samples are combined.
2. As pointed out earlier, the sub-stratification by means of the daily ΔH only (fig. 3) proves inadequate even without testing.
3. Testing the sub-stratification based on the 5-day mean ΔH index (figs. 5 and 6) involves testing the significance of the deviations of the ratios of Areas I, II, and III from that of its entire Group. Applying a Chi-square test to these deviations yields $\chi^2=21.39$ for 4 degrees of freedom. This means that there is less than one chance out of a hundred that such a distribution of proportions would occur by chance. So the evidence from the Chi-square test is that the distribution is a real one determined by the predictor variables.

From a theoretical standpoint, it is not necessary that like numbered Areas in figures 5 and 6 be coincidental, except under the following conditions: If the data in Groups 3 and 4 are drawn from two populations homogeneous in all respects except their overall passage to non-passage ratios, then the Areas in figures 5 and 6 should be coincidental. This is saying that the marginal variables in figures 5 and 6 (daily and 5-day mean ΔH) contribute alike in Groups 3 and 4. This seems likely, both from theoretical considerations and from the observed ratio distributions in the two figures, and would merit a test of significance. A χ^2 test may be applied to the deviations from the expected number of passage cases within Group 3, under the assumption that there is homogeneity between like areas in figures 5 and 6 except for the overall difference in ratios. These deviations are determined as follows:

	Group 4	Group 3			
			Number passage cases		
	Ratio*	Ratio*	Observed	Expected	Deviation
Area I	18/26	14/33	14	(14. 5)	−0. 5
Area II	11/14	6/24	6	(12. 0)	−6. 0
Area III	3/15	2/25	2	(3. 2)	−1. 2
Combined	32/55=.58	22/59=.37			

*Number passage cases/Total number cases.

The calculated value of χ^2 is 3.46 for 2 degrees of freedom. While a test of this sort is not particularly strong support of homogeneity between Groups 3 and 4 except for the overall ratio differences, on the other hand the hypothesis of homogeneity is not disputed.

In summary, as regards the testing of relationships contained in figures 5 and 6, it has been shown:

(1) That the Areas 1, 2, and 3 in both figures 5 and 6 are significantly different from each other.

(2) That there is no evidence against the hypothesis that the combination of the daily and 5-day mean ΔH variables contributes the same in like areas in both figures.

THE PROGNOSTIC 5-DAY MEAN ΔH INDEX

Thus far, the observed rather than the prognostic 5-day mean ΔH has been used for the development of the hypothesis. The usefulness of the hypothesis is limited by the degree to which the ΔH taken from the 5-day mean prognostic 700-mb. chart corresponds to the observed index.

It would appear that a forecast of a 5-day mean index of this sort is an unfair demand to be made upon the mean circulation forecasting technique presently in use. Thus, the question of accuracy of this forecast must be investigated carefully. A simple correlation between the forecast and observed ΔH is certainly pertinent, but in itself gives little indication of its usefulness for our purposes. One could conclude, however, that if the correlation approaches zero, then any further test of usefulness would have little meaning. If a positive correlation is found to exist, then it remains to be shown whether the correlation is high enough to be useful.

For the summer months, June, July, and August, 1947 through 1953, the correlation coefficient between the forecast and observed 5-day mean ΔH is .14 for 178 pairs of data.[3] This appears to be sufficiently high to warrant further investigation of usefulness.

[3] Very nearly significant at the 5% level. ($r_{.05}$ for 200 pairs of data=.14). It is interesting to note that the correlation coefficient for 98 pairs of data from the summers 1947–1950, inclusive, was .09, while for 80 pairs of data from the summers 1951–1953, inclusive, the correlation had increased to .35 suggesting considerable improvement in forecasts insofar as the particular index is concerned.

Only Groups 3 and 4 of the initial stratification are involved in the second phase of this test. The test was accomplished as follows:

Data which appear in figures 5 and 6 were relocated on their respective charts using the same daily value of the ΔH index, but using the prognostic 5-day mean rather than the observed. The area into which each particular case fell was then tabulated, using the area boundaries which had already been determined from the initial plot of the data. A comparison of results from observed data and prognostic data is given in table 2.

TABLE 2.—*Comparative results from figures 5 and 6 using observed 5-day data, and prognostic 5-day data. Ratios are number of frontal passage cases (numerator) and total number of cases together with equivalent percentages.*

	Area I 5-day data		Area II 5-day data		Area III 5-day data	
	Observed	Prognostic	Observed	Prognostic	Observed	Prognostic
Group 3	14/33 42%	14/43 33%	6/24 25%	4/16 25%	2/25 8%	4/20 20%
Group 4	18/26 69%	20/30 67%	11/14 79%	5/7 71%	3/15 20%	6/17 35%

It can be seen from table 2 that the relative percentage-wise ranking among the three areas for both Groups 3 and 4 is retained in changing from observed data to prognostic data. Also, the number of cases in each area remains much the same. The most significant difference appears to be the decreased range between the high percentage and the low percentage areas when the prognostic index is substituted for the observed. Since a large range (better separation) is the goal, this change is undesirable. The fact remains that by using prognostic data, even with its errors, a better separation is achieved than was possible in figure 3 without any additional modification.

CONCLUSION

It has been suspected for some time that large-scale and long-period circulation features exert influences on shorter period evolutions of features appearing on synoptic charts. However, up to the present time, no attempt to use this concept systematically or quantitatively has come to the attention of the author. A possible exception is the somewhat qualitative application contained in "Synoptic Weather Types of North America" by the California Institute of Technology, and similar typing systems.

It has been shown in the present paper that it is possible to incorporate into an objective forecast method rather simple measures of these large-scale controls, and thereby add information pertinent to the problem.

It is further demonstrated that there appears to be enough skill in the routinely prepared prognoses of these large-scale features to make these prognoses of use in this particular application. This is particularly true in view of the highly significant correlation between the observed and forecast 5-day mean ΔH for about the second half of the period considered (.35 for 80 pairs of data) in contrast with the first half.

The work done thus far has suggested many avenues for further research. A few of these are:

1. Discovering criteria for the selection of indices which would most effectively specify Grosswetterlage for application to a daily forecast problem.
2. The utility of longer period mean circulation patterns in daily forecasting problems, i. e., 30-day or some other less arbitrary period.
3. The possibility of stratifying both developmental and test data on the basis of Grosswetterlage with the aim of dealing with several homogeneous groups rather than with one heterogeneous group.

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